Parametric Optimization of Process Parameters For EDM of Stainless Steel 304

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By

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CERTIFICATE

This is to certify that the thesis entitled — **Parametric Optimization of Process Parameters For EDM of Stainless Steel 304** submitted to the National Institute of Technology, Rourkela (Deemed University) by **Narendra Kumar Patel Roll No. 212ME2297** for the award of the Degree of **Master of Technology** in Mechanical Engineering with specialization in **Production Engineering** is a record of bonafide research work conceded out by him under my supervision and direction. The result presented in this thesis has not been, to the best of my knowledge, submitted to any other university or institute for the award of any degree or diploma. The thesis, in my belief, has touched the standards fulfilling the requirement for the award of the degree of Master of technology in accordance with regulations of the Institute.

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ABSTRACT

In EDM various techniques are applied to improve the material removal rate (MRR), surface roughness (SR) and tool wear rate (TWR) with different electrode combination. However, the machining parameters are also effective while machining. In this study, an experiment is performed to analyze the effect of machining parameters viz. discharge current (Ip), pulse on time (Ton), voltage (v) over the responses of MRR and SR. For this Tungsten carbide tool or electrode used while the work piece chosen as AISI 304 stainless steel which is utilized for manufacturing of various products in our daily life. For the conduction of experiments L9 orthogonal array was used to complete the runs. We found that discharge current is most significant factor after that pulse on time over response of MRR and in case of SR the voltage is effective parameter. For analysis and explanations STATISTICA 9.0 software is used.

Keywords: Electrodes, Material removal rate, Surface roughness, Tungsten carbide.

ABBREVIATIONS

Symbol	Name
EDM	Electro Discharge Machining
MRR	Material Removal Rate
SR	Surface Roughness
Ip	Discharge Current
Ton	Pulse On Time
V	Voltage
µs	Micro second
µm	Micro meter
Mm	Millimeter
SEN	Sensitivity
ASEN	Anti-arc Sensitivity
A	Ampere
T_w	Tool work time
T↑	Tool lift time
DOE	Design of experiment

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Chapter 1

Introduction of EDM

1.1 History of EDM

Electrical Discharge Machining (EDM) was not completely in use benefit of this method until 1943. When established up how the erosive properties of the method could be employed and make use of machining functions. Once that one was discovered by Joseph Priestly in 1770, In the middle of 1980s machining process on EDM were converted to a production instrument. Effective movement through EDM makes it more commonly offered and also engaging above outdated machining procedures. At starting days EDM process was actually inaccurate plus damaged using letdowns. Commercially established in the mid-1970s, the wire EDM machining originated to be a feasible practice that facilitated to run-through the metallic operational industry we have seen nowadays.

Nowadays innovative changes in the area of non-traditional machining process are not to be considered as replacements for conventional machining methods of metal working. They also do not offer the best alternative solutions for all machining applications. The traditional metal cutting processes utilize shearing action on the work piece for material removal. However, the non-traditional processes depend on other factors such as chemical properties, melting and vaporization of the material, electrolytic displacement of ions and mechanical erosion. The main reasons for using the non-traditional machining processes are to machine high strength alloys, complex surfaces, difficult geometries, high accuracies surface finish and automation requirements.

EDM has been substituting traditional machining operations. Now today EDM is a popular machining operation in several manufacturing productions all over the world's countries. Most of the traditional machining process such as drilling, grinding and milling, etc. are failed to machine geometrically complex or difficult shape and size. Those materials are easily machined by EDM non-traditional machining process which leads to broadly utilized as die in addition to mold assembly industries, making aeronautical parts and nuclear instruments at the minimum cost. Electric Discharge Machining has also established its presence touched on the different subject areas such as make use of sporting things, medicinal and clinical instruments as well as motorized research and development regions.

1.2 Introduction of EDM

Electrical Discharge Machining is a most basic nontraditional machining process, where material is removed by thermal energy of spark occurring by means of repeated sequences of electrical ejections between the small gap of an electrode and a work piece. EDM is commonly used for machining of electrically conductive hard metals and alloys in automotive, aerospace and die making industries. EDM process is removing undesirable material in the form of debris and produce shape of the tool surface as of a metal portion by means of a recurring electrical ejection stuck between tool i.e. cathode and the work piece i.e. anode material in the existence of dielectric liquid. In this machining process work piece is called the anode because it is connected with positive terminal and electrode is connected with negative terminal i.e. called cathode. Dielectric fluid may be kerosene, transformer oil, distilled water, etc.

1.3 Principle of EDM

In this machining method the metallic particle is removed as of the work piece owed to controlled wearing away action by means of repeatedly occurring spark ejection with the help of discharge current applied by power supply taking place in small gap in the range of 10 –125 µm between the tool and work piece. The below schematic fig. 1.1 shows that the mechanical as well as electrical control system and electrical path for Electric Discharge Machining. A small break is kept among the tool and work piece through a servo control arrangement in which the tool in attached. Both the electrode and work piece stay immersed in a dielectric liquid. Kerosene/EDM oil/deionized water is use for liquid dielectric as a catalyst for the machining process.

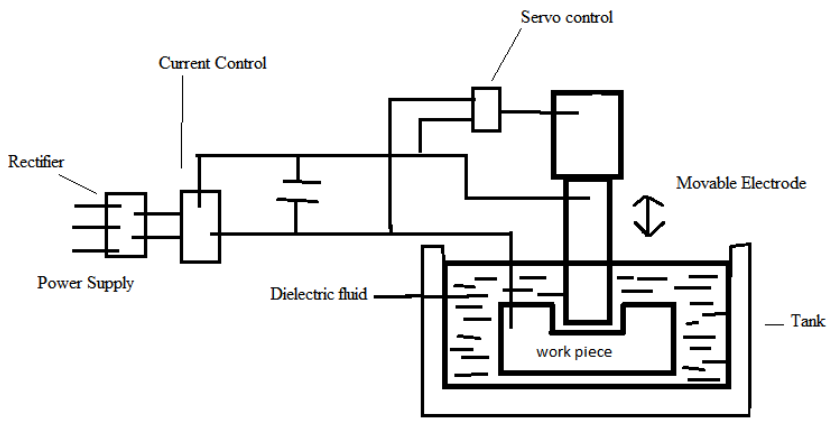


Figure1.1: Schematic setup diagram of Electric Discharge Machining [1]

This is shown in fig. 1.1 describes the schematic setup of Electric Discharge Machining for how the machining will do the work. The tool is attached to cathode terminal and the work piece is attached to anode terminal. After the potential differences apply by power supply crossways the small gap develops adequately high electrical discharges through the small break in the form of the spark in interval of 10 of micro seconds. Then the electron ions are present accelerated towards the positive ions, bringing on a discharge passage that turn out to be conductive. It is only at a given instant of time when the suitable voltage is built up across the tool and work piece the accelerated electron ions may ultimately collisions with the dielectric fluid molecules causing creation of a passage of plasma. An instant fall of the electrical resistance of the plasma passage permits that current density attains very large amounts, creating a rise of ionization between molecules and powerful magnetic field results of a very high temperature on the electrodes in the range of (10000 - 12000ºC). This high temperature spark causes sufficiently compressive force developed between work piece and tool as an outcome that more or less metallic particles are liquefied and eroded.

Plasma passage occurring exciting increase of temperature make use to remove material. Material removal takes place because of on the spot vaporization of the metallic particle as well as owed to melting process. The melted particle is not withdrawn altogether, however just partly. By means of the potential difference is drawn the plasma passage is no longer continued. As the plasma passage breakdown, it produces pressure force or shock waves, which clears the molten material by flushing method making a depression of removing material all over the place of the spark.

1.4 Classification of EDM

Mainly, there are two dissimilar kinds of EDM:

1.4.1) Die-sinking EDM

1.4.2) Wire-cut EDM

1.4.1 Die-sinking EDM

With the Die Sinker EDM Machining process, what in it happens, firstly the two electrodes are fitted on their places on the machine parts which is work bench and tool holder. Both the electrodes should be electrically conductive. After that both the electrodes are immersed in an insulating liquid dielectric with the help of pump. The dielectric is EDM oil/ kerosene / transformer oil. Then set the machining parameters on the CNC controller for machining on the work piece to get the required shape and size. The applied voltage initiate the current to discharge on to the work piece in the pulse form otherwise in continuous form it produces arc which is harmful for machining. Each spark energy is discrete and controlled enough to melt and vaporize within a thin gap from the work piece surface. In this period the discharge current is varied within range of 0.5 to 400 A, at 40-300 V applied voltage range and pulse duration can be varied from 2 to 2000 micro second. Different type of flushing method is applied to remove and prevent from accumulation of melted material from the work piece and smoothen the process.

1.4.2 *Wire-cut EDM*

Wire EDM also called electric discharge wire cutting process used for producing two or three dimensional complex shapes using an electro thermal mechanism for eroding the material from a thin single stranded by guide rulers metal wire surrounded by deionized water which is used to conduct electricity. Any hard material can cut by wire EDM process, but the material should have an electrical conductive properties.

The electrode wire is commonly made of brass or copper material. The diameter range of wire is 0.5 to 0.25 mm. The wire is wound on a two wire spool which is rotated in the same direction to strand the wire. The speed of wire movement is up to 3 m/min. The spark is generated between moving electrode wire and the work piece, thereby removing the material. The dielectric is localized rather than submerging the whole work-piece. It is utilizing CNC controlled machine set up to process the machining operation.

1.5 Some Machining Parameters of EDM

(a) **Pulse On time (Ton):** It is the duration of time expressed in micro seconds in which the peak current is ready to flow in every cycle. This is the time in which energy removes the metallic particles from the work piece.

(b) **Pulse Off time (Toff):** It is the period of time expressed in micro seconds between the two pulse on time. This time permits the melted particle to coagulate on to the work piece and to be wash away by flushing method of the arc gap.

(c) **Arc gap:** It is gap between the electrode and work piece in which the spark generate for eroding the metal from the work piece. It is very thin gap in the range of 10 – 125 µm.

(d) **Discharge current (Ip)**: Current is measured in ampere (A). Discharge current is responsible directly for material removal. It contains energy for melting and evaporation.

(e) **Duty cycle (τ):** It is a ratio of the pulse on-time relative to the total cycle time expressed in percentage. This factor is calculated by dividing the on-time by the total cycle time (on plus off time).

(f) **Voltage (V):** It is a potential difference that can be applied by the power supply in a controlled manner. Voltage is also another main factor which affects the material removal.

(g) **Diameter of electrode (D):** It is the diameter of electrode or tool material. Diameter of tool is one factor considered on machining. This experiment 10 mm tool diameter is utilized.

(h) **Over cut** – It is a measurement of clearance between tool and work piece after completing each experiment by outline of the tool material.

1.6 Characteristics/Specification of EDM

EDM description by machinery practice, material removal rate and additional purpose that presented in this table no. 1.1

Table1.1 Specification on EDM

S.N.	Characteristics	Range
1	Mechanism of process	Controlled erosion i.e. melting and evaporation aided by cavitation
2	Spark gap	10 - 125 µm
3	Spark frequency	200 – 500 kHz
4	Peak voltage across the gap	30 - 250 V
5	Maximum material removal rate	5000 mm^3/min
6	Specific power consumption	2-10 W/mm^3/min
7	Dielectric fluid uses	EDM oil, Kerosene and water with Glycol, silicon-based oil, deionized water, hydrocarbon fluids etc.
8	Electrode material	Copper, Brass, Graphite, Cu-Graphite alloys, Cu-W alloys, Zinc alloys, Tungsten.
9	MRR/TWR	0.1-10
10	Materials application	All electrically conductive metals and alloys can be machined.
11	Shape application	Micro-holes for nozzles, thin slots, visionless complex craters.

1.6 Dielectric fluid

The dielectric fluid is a catalyst conductor, coolant and also a flushing medium.

The requirements are:

1. The dielectric should have necessary and constant dielectric strength to serve as insulation between the tools and work till the breakdown voltage is reached.
2. It must be de-ionizing quickly afterwards the spark ejection has taken place.
3. It must need little viscosity and a decent moistening ability to provide effective cooling mechanism and remove the swarf particles from the machining gap.
4. It should flush out the particle produce during the spark out of the gap. This is the most important function of the dielectric fluid. Inadequate flushing can result in arcing decreasing the life of the electrode and increasing the machining time.
5. It should be chemically neutral so as not to attack the tool, the job, the movable table or the tank.
6. Its flash point should be high so that there are no fire threats.
7. It should not release any toxic vapors.
8. It should maintain these properties with temperature variation, contamination by working residuals and products of decomposition.
9. It should be economical and easily available.

The experimentation has been done by using commercial grade of EDM oil whose specific gravity= 0.763, freezing point= 94ºC used as a catalyst liquid. It is recycled for each experiment by pump. It is works as a coolant and intermediate carrier of molecules between work piece and tool during spark erosion process.

1.8 Flushing method

Flushing is the greatest key role which provides correct circulation of dielectric liquefied in any electrical discharge machining operation. If removed particles are not flushed thoroughly, they act as obstacles in the small gap between tool and work piece. Flushing is the procedure of presenting clean strained dielectric liquid into the spark gap. There are a number of flushing systems used to take out the metal constituent part well such as pressure flushing, side flushing, and suction flushing. In this experiment we are using side flushing to clean the small gap.

1.9 Application of EDM

1. The EDM process is extensively used because of its many advantages over traditional machining. Its chief applications are in the manufacture of press tool and forging dies as well as molds making for injection moulding.

2. EDM has also successfully employed for producing intricate and irregular shaped profiles or outline common in tool rooms.

3. Small diameter holes in carbide or hardened steel can be machined by tube type electrodes of copper tungsten, using a micro machining attachment.

4. Internal threads and internal helical gears can be cut in hardened materials by using a rotary spindle along with thread cutting.

5. Another field of application of EDM is in grinding process is similar to EDM except that the electrode is rotating wheel of graphite or brass.

6. EDG is advantageously adopted in grinding steel and carbide, thin and fragile sections, brittle materials etc.

7. In travelling wire EDM has a wire guide and tensioning device to permit continuous feeding of the expendable brass or copper wire electrode of diameter 0.2 mm or less.

8. Wire EDM well suited in the production of extrusion dies, blanking dies and punches.

1.10 Advantages of EDM

(i) In EDM process materials having electrical conductive property can be cut easily.

(ii) With the help of CNC device systems on die sinking EDM machines, complex objects can be machined. Intricate dies and molds can be shaped precisely, more rapidly, and at lesser costs.

(iii) There is three axes movements, i.e. x, y, and z available to allow for the manufacturing of intricate profiles on the work piece.

(iv) Case-hardened objects can be machined for removing the distortion caused by heat treatment process.

(v) Forces produced in the cutting process for material removal is negligible.

(vi) Tinny stiff segments for example net or fins can be with no trouble machined without distorting the part.

1.11 Limitation of EDM

(a) Both the material the tool and work piece material has to be electrical conductivity property. Because of this property creation of electric discharges is possible.

(b) Sometimes the wear rate on the electrode or tool is higher which requires use of more than one tool to finish the machining on the work piece.

(c) Sometimes the measurement of thin gap between the tool and work piece is not easily predictable especially in case of complex geometries which demands the flushing method to be differ from the simple one.

(d) Optimum machining settings of the EDM process largly be influenced by on the grouping of the tool and work piece. EDM manufacturers only fund these settings of the required material combination. Therefore skill personnel required to develop his own technology.

(e) In case of die sinking EDM the cavity formed on the work piece with low metal removal rate. In case of wire-cut EDM only outline of the required shape on the work piece has to be machined. Therefore EDM is limited to small production applications.

Chapter 2

Literature survey

Some survey on research papers require to deliberate in this chapter connected towards Electrical Discharge Machining. From the readings out in these papers and thesis is mostly concerned through the EDM settings such as the discharge current, applied voltage, pulse on time, pulse off time, duty cycle, etc. and in what way these parameter will affect the machining outputs like MRR, Ra, TWR etc.

B. Sidda Reddy et al. [2] studied that influence by design four factors such as current, servo control, duty cycle and open circuit voltage over the outputs on MRR, TWR, SR and hardness on the die-sinker EDM of machining AISI 304 SS. They had been employed DOE technique with mixed level design and analyze for performing a minimum number of runs. They achieved that for higher MRR, the current, servo and duty cycle should be fixed as high levels and 95% confidence level with descending order in case of TWR with same factors.

M.M. Rahman et al. [3] experimentally found out the machining characteristic of austenitic stainless steel 304 through electric discharge machining. The investigation shows that with increasing current increases the MRR and surface roughness. The TWR increases with peak current until 150 µsec pulse on time. And from the results they were found for copper electrode al long pulse on time no tool wear with reverse polarity.

S. K. Dewangan [4] investigated the effect of machining parameter settings like pulse on time, discharge current and diameter of tool of AISI P20 tool steel material using U-shaped copper electrode with interior flushing technique. Experiments were conducted with the L18 orthogonal array based on the Taguchi method. Moreover, the signal-to-noise ratios associated with the observed values in the experiments were determined by which factor is most affected by the Responses of Material Removal Rate (MRR), overcut (OC) and Tool Wear Rate (TWR).

S. H. Tomadi et al. [5] analyzed that effect of machining settings of tungsten carbide on the outputs such as TWR, MRR and Surface finish. Confirmation test performed to evaluate error between predicted values and by experimental runs in terms of machining characteristics. They were found out copper tungsten tool use for better surface finishing of the work piece. They were using full factorial DOE for optimization and found out with greater pulse off time lesser tool wear of tungsten carbide and with current, voltage and pulse on time increment tool wear increased.

AKM Asif Iqbal and Ahsan Ali Khan [6] optimized the machining process parameters for the EDM milling operation of a stainless steel work piece with copper tools. Input parameters are RPM of tool, feed rate and voltage while the outputs are MRR, TWR and Ra. Central composite design is utilized for optimization to get higher MRR, TWR and Ra. From the results the machining settings for optimal condition are done at 1200 RPM, voltage 120V and feed rate 4µm/Sec.

Norliana Mohd Abbas et al. [7] reviewed the trends of various research on EDM such as ultrasonic vibration assisted EDM, dry EDM, powder mixed EDM, water based EDM and various modeling techniques of EDM to precise and accurately EDM performance. They found that ultrasonic vibration assisted EDM is suited for micro machining, dry EDM is cost effective, water based EDM provides safe and conductive working environment, powder mixed EDM provides increasing surface quality, MRR and TWR.

Singh et al [8] investigated the influence of machining settings such as peak current on MRR, overcut, TWR and Ra in EDM of E31 tool steel heat treated with different tools such as copper, brass, aluminum and copper tungsten. From results copper and aluminum electrode gives higher MRR, Overcut in diameter is minimum with this tools.

Sanjeev Kumar et al [9] reviewed on the new uses of electrical discharge machining (EDM) process, with certain prominence on the prospective of this process for surface alteration. Above and beyond removal of work material during machining, the fundamental nature of the process results in erosion of tool material also. Creation of the plasma passage containing of material vapors from the eroding work material and tool electrode; and pyrolysis of the dielectric affect the surface composition after machining and hence, its properties. Deliberate material transfer may be carried out under specific machining conditions by using either composite electrodes or by a break up metallic powders in the dielectric or both. In this review on the wonder of surface modification by electric discharge machining and upcoming leanings of its applications.

B. Bhattacharyya et al. [10] Experimented on EDM using the development of a mathematical model based on RSM for correlating the interactive and higher order effect on machining parameter such as peak current and pulse on time of surface integrity of M2 Die steel machined through analysis of EDM parameters on surface roughness, white layer thickness and surface crack density. With the developed model the optimal combination evaluated for minimizing the surface integrity.

Dhar et al [11] developed a second order nonlinear mathematical model to establish the relationship between machining settings. And ANOVA has been performed to verify the fit and adequacy of the model. Process parameters on EDM are current, pulse on time and gap voltage over the responses of MRR, TWR and ROC of a composite material with brass tool having 30 mm cylindrical diameter.

I. Puertas et al. [12] Investigated the attention on the die-sinking EDM with an adequate selection of machining condition is the most important aspects of the machine. They were found that the impact of the features of intensity, pulse on period and duty cycle over cemented carbide or hard material such as 94WC-6Co. They determine characteristics: TWR, MRR and Ra by mathematical simulations will be achieved with the DOE method combined with multiple regressions has been effectively applied to modelling for optimal machining condition. When intensity or pulse times were increased, the roughness value also increased. With tungsten carbide low values should be used for both intensity and pulse time.

J. Simao et al [13] investigated work on the surface alloying of the different work piece on machining over EDM. In experiments powder metallurgy made tools and use of powders suspended in dielectric liquid. Based on experimental results the use of primary sintered electrodes made from tungsten carbide resulted in the formation of a uniform modified surface layer with some micro cracks and an average thickness of up to 30 µm.

T. M. Chenthil Jegan et al [14] determines the assortment of machining settings like peak Current, Pulse on time, Pulse off time in EDM intended for the machining of AISI202 stainless steel metal. They were using of grey relational analysis technique to optimizing the machining parameters MRR and SR is introduced. The greatest nominal influence in addition to the order of significance of the manageable influences to the multi performance physical characteristics on EDM machining procedure stayed determined. The results show that Discharge current was the main parameter affecting the MRR.

S. Jai Hindus et al [15] done experimentations by way of the Box Behniken design. The effects show that TWR and MRR are deeply affected using Pulse on time and current (A). Cylinder-shaped copper tool ensuring a dimension of diameter of 13 mm is castoff to machining of stainless steel 316 L work piece. On MRR the greatest weighty cause was found to be Pulse on time trailed by peak current (A) and the smallest significant was gap voltage. The MRR increased linearly with the increase in current (A). For tool wear the most significant factor was current (A) followed by Pulse on time (t_w) and also laterally with the increase in voltage.

T. Rajmohan et al [16] experimented using design of experiment technique under L9 orthogonal array design and considering the effect of machining parameters of EDM such as pulse on time, pulse off time , current and voltage on MRR in machining of AISI304 stainless steel. For optimization they had been used signal to noise ratio and analysis of variance to analyze the effect of the parameters on MRR and also optimize the cutting parameters.

M. Kiyak and O. Cakır [17] examined that the influences of EDM settings on surface roughness for machining of AISI P20 tool steel. Discharge current, pulses on time and pulse pause time are the selected parameters. They were found that surface roughness of work piece and tool were influenced by discharge current and pulse time with increasing values SR increased and with lower value and higher pulse pause time a good surface finish achieved.

M. S. Reza et al [18] optimize the controlled parameters of EDM using injection flushing type machining on multi performance characteristics using GRA method. Parameters are optimized on different Response such as MRR, TWR and SR. For this experiment copper tool and AISI 304 stainless steel work piece is utilized. L18 Taguchi's orthogonal array design planned for experiments. Selected machine settings are Ip, Ton, polarity, voltage, dielectric liquid pressure and machining depth have been taken.

Ashok Kumar et al [19] investigated machining of EN-19 tool steel using U-shaped tubular copper tool with internal flushing by EDM. Taguchi's L18 OA design utilized for all runs. They found that MRR increases when current increases with reduction on pulse on time, TWR increases with pulse on time increment and overcut is increases with current increment.

P. Srinivasa Rao et al [20] has been developed the mathematical model for predicting die-sinking EDM of AISI 304 stainless steel work piece on response such as TWR, MRR, Ra and HRB using fuzzy logic modeling. A regression analysis of experimental and predicted output was performed to investigate the model. With fuzzy rule relationship was establish through experimentation to reduce the no. of runs.

S. Abdurrehman Celik [21] applied different parameters on a work piece made of powder material. They found that lower surface roughness value measured on the powder material. With different use of electrode not much influence the surface roughness.

Objective of the study:

1. The objective of the present study is to investigate the effect of the machining variables viz. discharge current, pulse on time and voltage on output performances such as MRR, SR during machining of AISI 304 stainless steel work piece by using Tungsten Carbide tool material.
2. Based on experimental results, an optimization of machining variables can be perform and analyze by STATISTICA 9.0.

Chapter 3

Experimentation

To start machining having discussion of an investigational work designed earlier just before the implementation of machining. This one concerns a L_9 orthogonal array by using design of experiments from Taguchi's method, choice of work piece, selection of tool, investigational set-up then by using the data of experiments calculation made for Material Removal Rate (MRR) and Surface Roughness (SR).

3.1 Investigational set up

The experimentations be there performed by operating on Electric Discharge Machine classified as (die-sinking type) ELECTRONICA -ELECTRAPLUS PS 50ZNC whose polarization on the electrode be located as negative whereas that of work piece be located as positive. The dielectric liquid recycled was EDM oil having specific gravity - 0.763. The EDM machine contains with the following measures:

1) For circulation of dielectric there is reservoir at base, pump and valves for passage.

2) Power supply unit and CNC functions.

3) Leak-proof tank along with tool fixing chuck.

4) Two dimension movable table by lever.

5) Tool holding device.

6) Servo control unit for vertical movement of the tool.

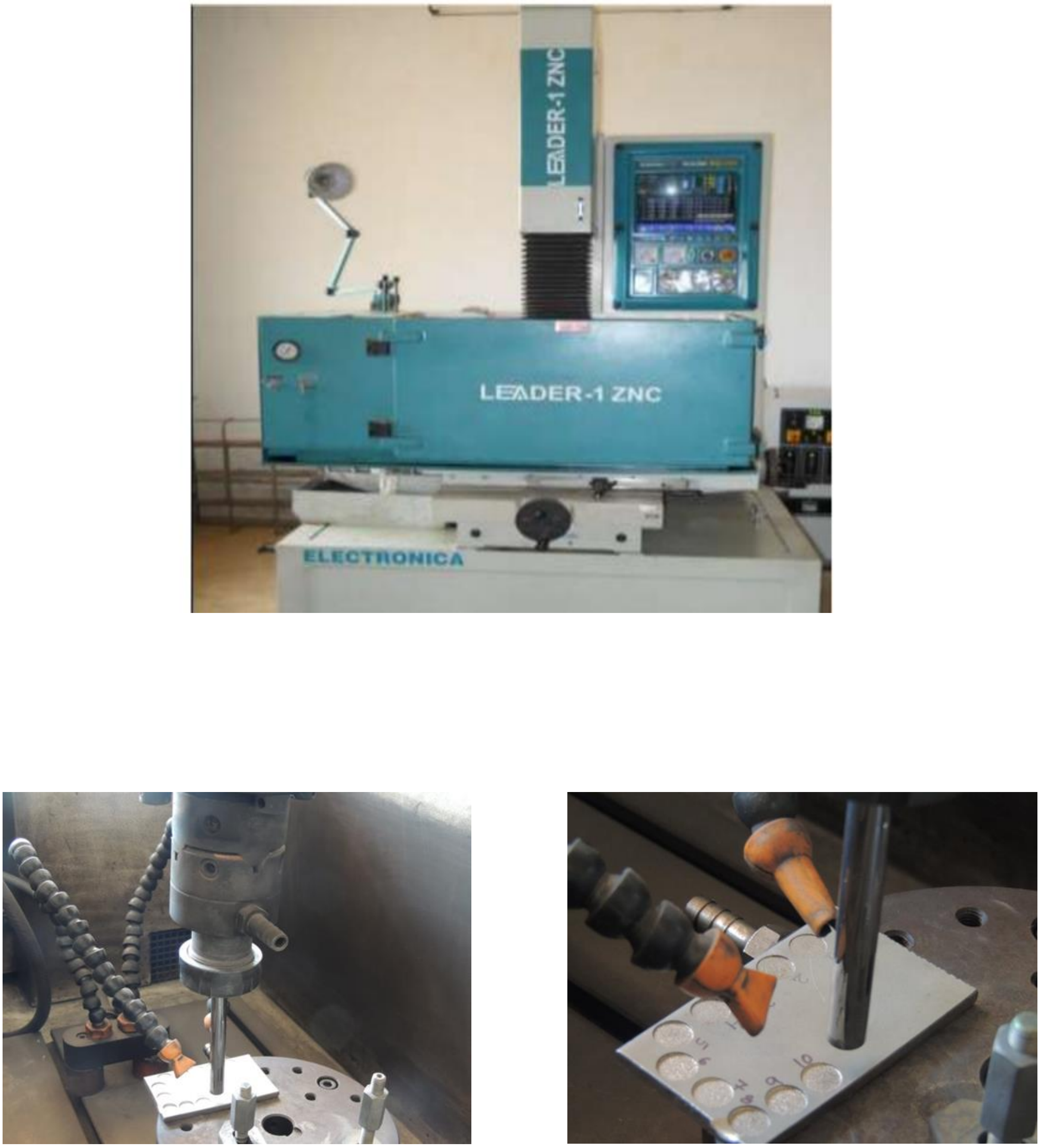


Fig. 3.1: Die Sinker EDM machine setup with tool and work piece (Model: ELECTRONICA -ELECTRAPLUS PS 50ZNC)

3.2 Selection of work piece

In this experiment AISI 304 stainless steel of size 80×50×5 mm^3 plate is chosen for conducting the experiment. Grade 304 is the commonly used stainless steel; it is the utmost versatile applications and greatest use of stainless steel, offered in an extensive variety of good products, practices and qualities than any other. It has wonderful welding and forming characteristics. Grade 304 is freely brake or spool molded into a variability of work uses in the manufacturing, construction as well as automobile fields. The austenitic configuration provides these grades brilliant toughness, straight down to lower hotness.

It has excellent oxidization prevention in a numerous range of full of atmosphere environments as well as lots of corrosive medium. It has good corrosion resistance in intermittent service and brilliant weld ability property in entirely available standard fusion methods, both with and without filler methods shown in fig. 3.2. Therefore it is applicable to make kitchen appliances, sinks, benches, architectural paneling, railings, heat exchangers, threaded fasteners, spring, chemical containers including for transport etc.

Table 3.1: Structure varieties for AISI 304 mark stainless steel

Grade		C	Si	P	S	Mn	Cr	Ni	N
304	Minimum	-	-	-	-	-	18.0	8.0	-
	Maximum	0.08	0.75	0.045	0.030	2.0	20.0	10.5	0.10

Table 3.2: Mechanical properties of AISI 304 grade stainless steel

Grade	Tensile Strength (Mpa) min.	Yield Strength 0.2% proof (Mpa) min.	Elongation % (in 50 mm) min.	Hardness	
				Rockwell(B) Max.	Brinell(HB) Max.
304	515	205	40	92	201

Fig. 3.2: AISI 304 stainless steel work piece before machining

3.3 Selection of tool material

In this experiment Tungsten carbide rod of 10×100 mm^2 used. Tungsten carbide products are famous for their heat resistance, toughness and good machinability. One of the products of tungsten carbide are the solid tungsten carbide rods that are used for cutting dissimilar alloys, cast iron, stainless steel, refractory alloy steel, nickel based alloy, titanium alloy and other nonferrous metals.

The solid tungsten carbide rods are offered as a ground and unground with metric or inch standards. These rods possess the features of good wear resistance and corrosion resistance. The other uses of these rods are as HSS cutting tool, carbide end mills, aerospace cutting tool, carbide drills, milling cutter, electronic cutter, gun barrel, metal cutting saw and several other applications. Tungsten carbide (WC), alternatively, is a composite of W and C. Subsequently most of the commercially essential cemented carbides are constructed on WC as per the rigid part, the terms "tungsten carbide" as well as "cemented carbide" are every so often used interchangeably. Tungsten carbide as a metal composite is significant for its robustness with highest melting point of all the elements as shown in fig. 3.3.

Fig. 3.3: Tungsten carbide electrode or tool

3.4 Mechanism of MRR

Mechanism behind material removal of EDM process is based on the conversion of electrical energy to thermal energy that categorized it to electro thermal process. During machining both the surfaces may have present smooth and irregularities causes minimum and maximum gap in between tool and work piece. At a given instant at minimum point suitable voltage is developed produces electostatic field for emmision of electrons from the cathode there electrons accelerated towards the anode. After getting velocity of electrons collides with the dielectric molecules breaking them into negative and positive ions. Because of that spark is generated with high temperature causes melting and vaporization of material from the workpiece as shown in figure 3.4 and made the shape of tool on to the workpiece.

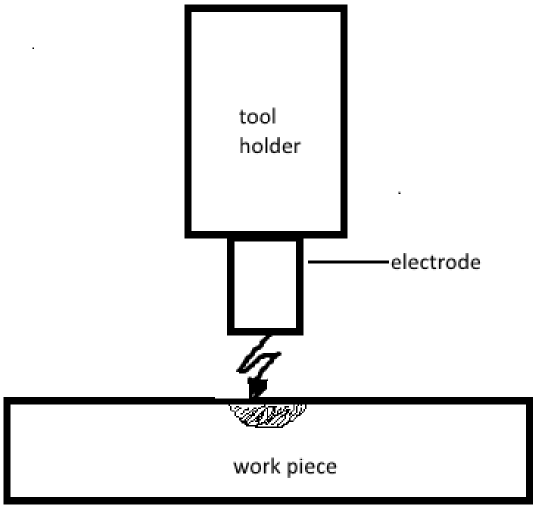


Fig 3.4: Crater formation in EDM process

3.4.1 Formula of MRR calculation

MRR is calculated as the proportion of the change of weight of the work piece before and after machining to the product of machining period and density of the material.

$$\text{MRR} = \frac{Wbm - Wam}{t \times \rho}$$

Whereas:

Wbm = Weight of workpiece before machining.

Wam = Weight of workpiece after machining.

t = Machining period = 10 min.

ρ = Density of AISI 304 stainless steel work piece = 8000 kg/m^3

3.5 Measurement of Surface Roughness

Surface Roughness is the size of the surface texture. It is expressed in μm and denoted by Ra. If the value comes higher that means the surface is rough and if lower comes that means that the surface is smooth. The surface roughness values are measured by means of an apparatus portable type profilometer, Talysurf (Model: Surtronic 3+, Taylor Hobson) shown in fig. 6.3. After measurement calculate by arithmetic mean of three data is in use as the absolute value**.**

3.6 Taguchi design

Dr. Genichi Taguchi's approach or DOE is highly effective wherever and whenever it is suspected that the performance of a part or process is controlled by more than one factor. The main purpose is to give a clear understanding to make the DOE technique more effective in applications, and how relate the outcome of the technique to improve the quality of products and processes. When used for product design optimization, analytical simulation is the common approach, because hardware is not often available.

3.6.1 Taguchi design experiments in STATISTICA 9.0

STATISTICA 9.0 offers many possible ways in which an experiment can be carried out. A number of ordinary orthogonal arrays have been created to ease of experimental design. For each of these arrays can be used to design experiments to suit numerous experimental situations. A number of orthogonal arrays, such as L_4, L_8, L_9, L_{12}, L_{16}, L_{18}, L_{27} and so on, created for two or three level factors. STATISTICA 9.0 estimates response tables and creates main effects and S/N ratios plans intended for:

1 S/N ratios [Signal-to-noise ratios] vs. control factors.

2 Means vs. control factors.

A taguchi design or an orthogonal array method is designing the experimental procedure using different types of design like, two, three, four, five, and mixed level. In this study, a three factor mixed level setup is chosen with an overall nine numbers of trials to be conducted and hence the OA L_9 be there selected. As a few more factors are to be added for further study with the same type of material, it was decided to utilize the L9 setup, which in turn would reduce the number of experiments at the later stage. In addition, the comparison of the results would be simpler.

The levels of experiment parameters and discharge current (Ip), spark on time (Ton) and applied voltage (V) are shown in Table 3.3 and the design matrix is represented in Table 3.4.

Table 3.3 Machining parameters and their level

Machining parameter	Symbol	Unit	Levels		
			Level 1	Level 2	Level 3
Discharge current	Ip	A	5	7	9
Pulse on time	Ton	μs	50	150	200
Voltage	V	V	45	55	65

3.7 Conduct of Experiments

Tungsten carbide tool material individual was used having 10 mm solid diameter and 100 mm length. And the die-sinking type PS50 ZNC EDM machine is used. Marketable grade EDM oil (specific gravity= 0.763, freezing point= 94˚C) was used as dielectric liquid to perform the experiment. Side flushing with nozzle was recycled to flush away the eroded materials from the sparking zone. In this experiment duty cycle is kept constant 5. For a three level factor are attempted with an overall number of 9 trials completed on die sinking EDM.

The calculation of material removal rate has been done by using electronic sense of balance weight machine as displayed in Fig 6.4. For each weight measurement first soak the work piece from paper or cloth to prevent from extra weight measurement. This machine having capability measure weight up to 300 g and accurateness is 0.001 g.

3.8 Design matrix and Observation table

Table 3.4: Design matrix and Observation table

Run	Ip	Ton	Voltage	Wt. of work piece (in gm)	
S. No.	(A)	(μs)	(V)	Wbm	Wam
1	5	50	45	150.592	150.356
2	5	150	55	150.356	150.030
3	5	200	65	150.030	149.758
4	7	50	55	149.758	149.371
5	7	150	65	149.371	148.886
6	7	200	45	148.886	148.358
7	9	50	65	148.358	147.883
8	9	150	45	147.883	147.145
9	9	200	55	147.145	146.464

3.9 Conclusion of experimentation

Experimentations be there accompanied according to Taguchi design method by using the machining set up and the solid tungsten carbide rod electrodes with side flushing. The control parameters are discharge current (Ip), pulse duration (Ton) and voltage (V). Experimentations were varied to complete 9 altered trials and the weights of the work piece for calculation of MRR and with the help of profilometer surface roughness (Ra) have been measured.

Chapter 4

Result and Discussion

In this chapter, we are discussing about the effects or influence of machining parameter, i.e. Discharge current, Pulse on time and voltage on material removal rate(MRR), surface roughness (SR) of AISI 304 machined work piece with tungsten carbide tool and find out which parameter is most important during an experiment with the help of Taguchi design.

4.1 Response Table:

Table 4.1 shows the Response and calculation for MRR and SR along with the input parameters or factors.

Response Table 4.1

Run no.	Ip (A)	Ton (µs)	Voltage (V)	MRR (mm^3/min)	SR (µm)
1	5	50	45	2.9500	5.9333
2	5	150	55	4.0750	7.1333
3	5	200	65	3.4000	8.4000
4	7	50	55	4.8375	5.2667
5	7	150	65	6.0625	7.8000
6	7	200	45	6.6000	7.1333
7	9	50	65	5.9375	8.4000
8	9	150	45	9.2250	4.2000
9	9	200	55	8.5125	4.6667

From the above design matrix I have conducted the nine experiments from EDM machine with machining time 10 min. taken for each experiment. The impact on the work piece by machining process is shown in the below figure 4.1.

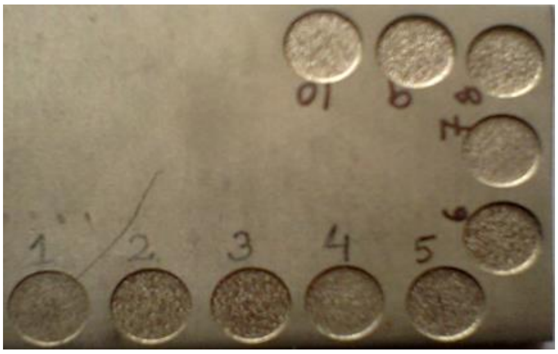


Fig. 4.1: AISI 304 stainless steel work piece after machining

4.2 Influences on MRR

The S/N ratios for MRR are calculated as given in Equation [1]. Taguchi method is used to analysis the result of response of machining parameter for “larger is better” criteria.

LB: $\eta = -10 \log [\frac{1}{n} \sum_{i=1}^{n} yi^{-2}]$ [1]

Where η denotes the S/N ratios calculated from observed values, yi represents the experimentally observed value of the i^{th} experiment and n=1 is the repeated number of each experiment in L-9 Orthogonal Array is conducted.

With full factorial as a design of experiment, value of surface roughness for each sample will be obtained. Then, STATISTICA 9.0 software will be used for further analysis. Figure 4.2 to 4.4 shows all the result.

From the mean plots of figure 4.2, figure 4.3 and figure 4.4 indicates that MRR at 9 A discharge current, 150 µs pulse on time and at voltage of 45 V voltage respectively gives the best results on input parameters.

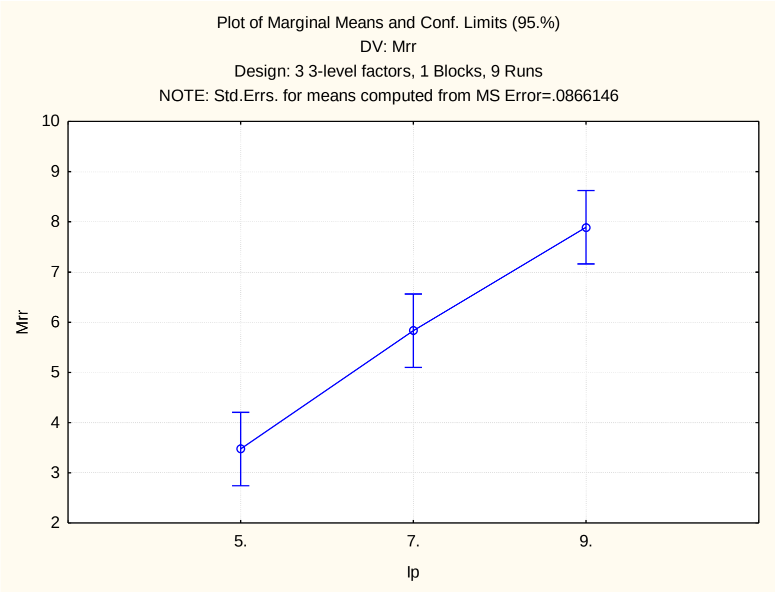


Fig: 4.2: Mean plot of MRR (mm^3/min) versus Ip(A)

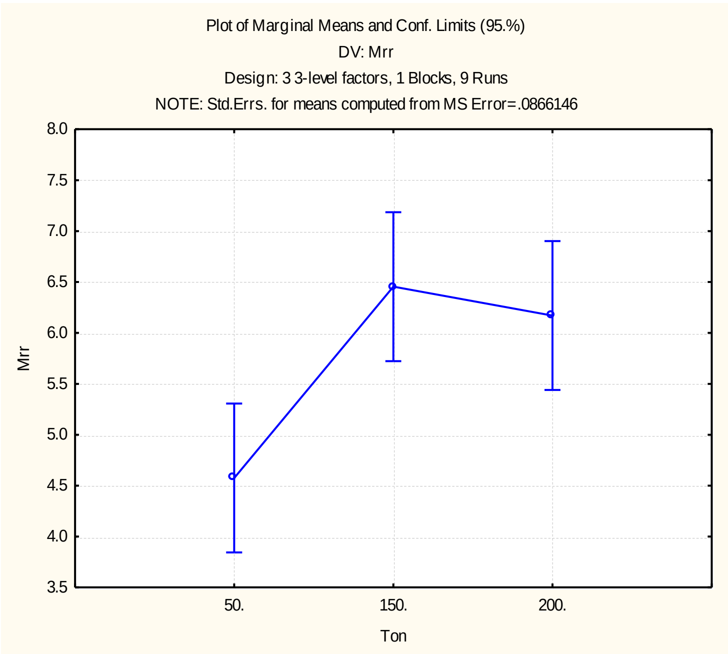


Fig 4.3: Mean plot of MRR (mm^3/min) versus Ton(µs)

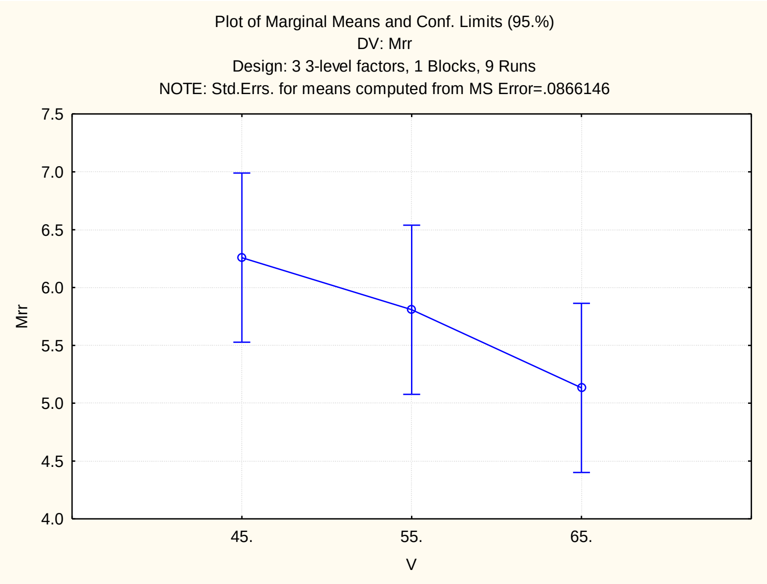


Fig 4.4: Mean plot of MRR(mm^3/min) versus voltage(v)

From the Analysis of variance studied for the effect of factors on MRR is indicating in Table 4.2 which obviously shows that the discharge current is the most significant factor while machining of AISI 304 SS with tungsten carbide tool. After that pulse on time is an important parameter and voltage is not significant factor during machining. Figure 4.5 shows that the main effects of S/N ratios on MRR by the factor. For this case "higher is better" is chosen.

Table 4.2 ANOVA of S/N ratios for MRR

Effect	Analysis of Variance (MRR) Mean = 14.5931 Sigma = 3.40187				
	SS	df	MS	F	P
1 Ip	76.42654	2	38.21327	1857.607	0.000538
2 Ton	14.00673	2	7.00337	340.445	0.002929
3 V	2.10735	2	1.05367	51.221	0.019149
Residual error	0.04114	2	0.02057		

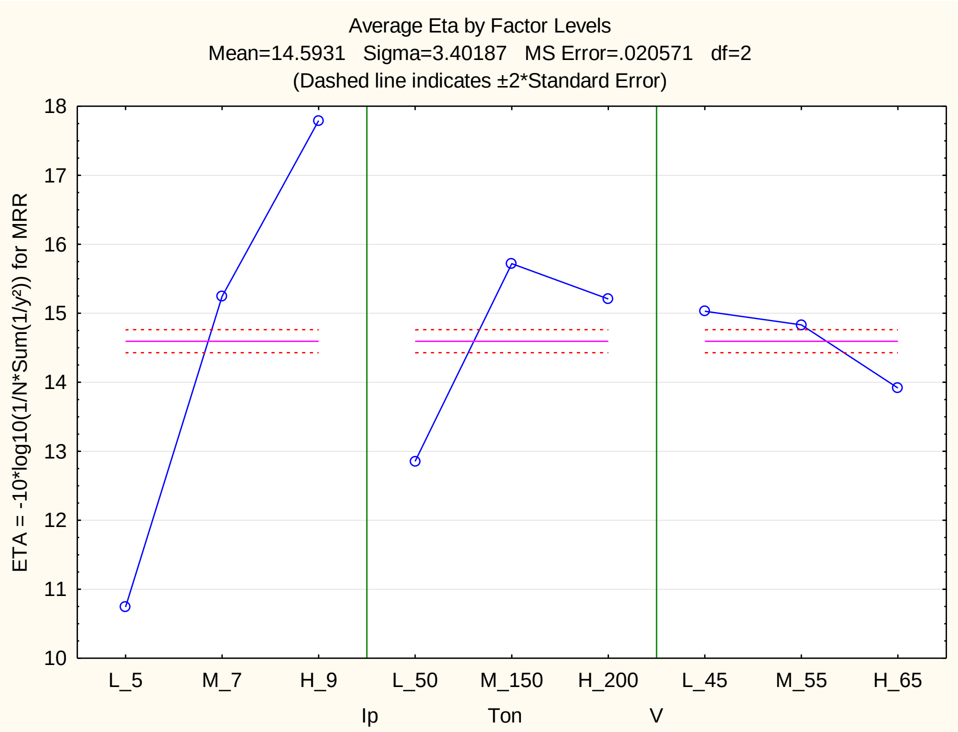


Fig. 4.5: S/N ratio plot of MRR

4.3 Influences on Surface Roughness

The S/N ratios for SR are calculated as given in Equation [2]. Taguchi method is used to analysis the result of response of machining parameter for smaller is better (SB) criteria.

SB: $\eta = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} yi^2\right]$ [2]

According to Figure 4.6, Figure 4.7 and Figure 4.8 shows that the SR at 7 A of discharge current, 50 µs of pulse on time and at voltage of 55 V respectively gives the best results for surface roughness (µm) is obtained.

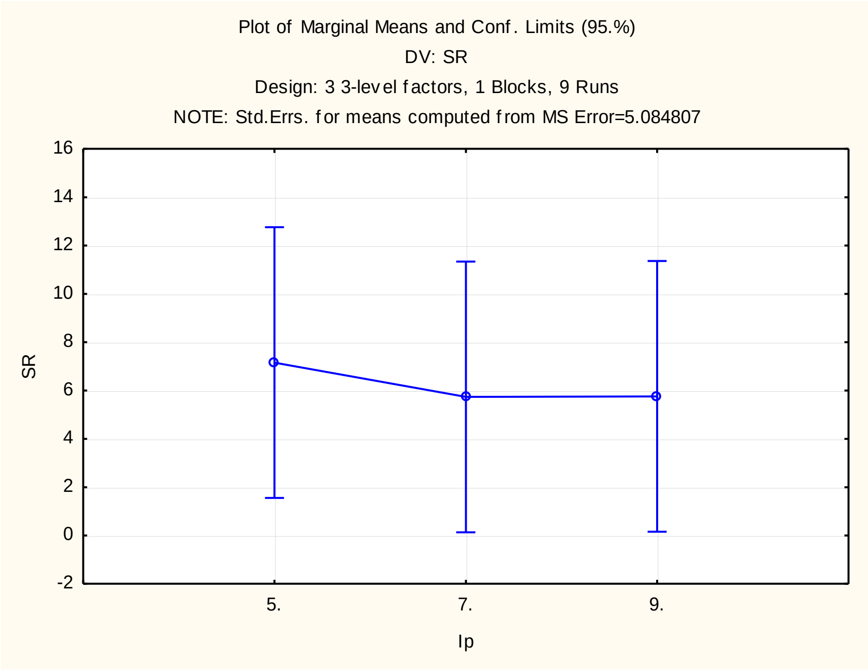


Fig: 4.6: Mean plot of SR (μm) versus Ip (A)

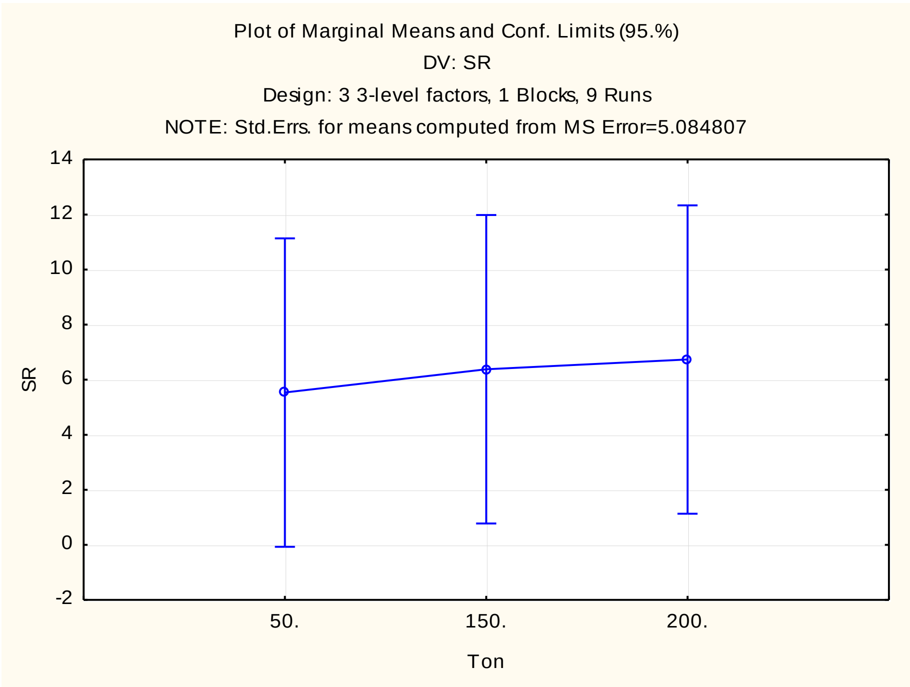


Fig: 4.7: Mean plot of SR (μm) versus Ton(μs)

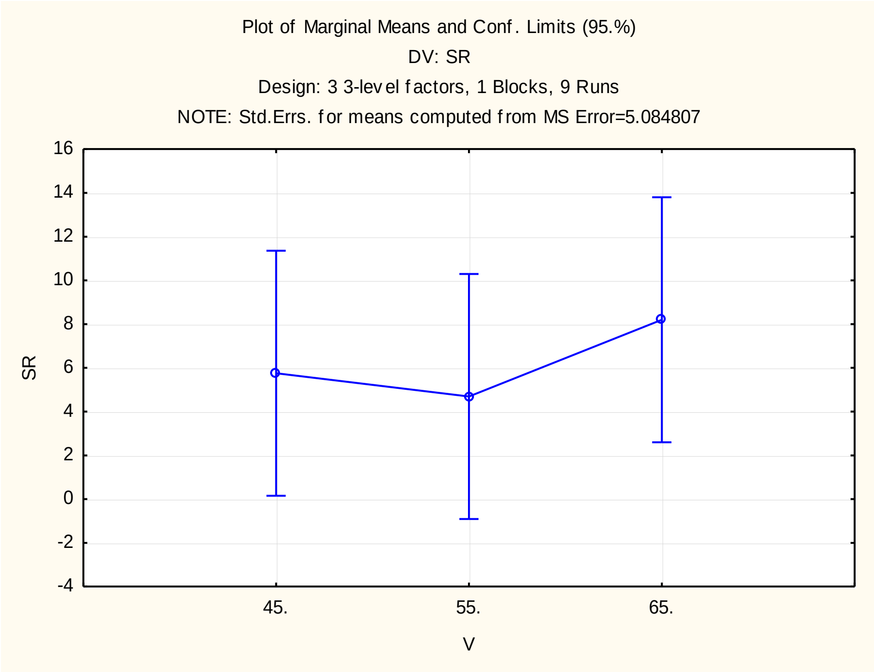


Fig: 4.8: Mean plot of SR (µm) versus Voltage (v)

To know the statistical validity of the developed experimental setup on ANOVA analysis (Table 4.3) is performed, R^2 value 71.65 states that the significance of the model and percentage contribution of voltage is about 65.64% states the impact of voltage on surface roughness of the work-piece in EDM process. The parameters such as discharge current (Ip) and pulse on time (Ton) has very less impact on surface quality of the work-piece. The analysis states that the effectiveness of the voltage on the EDM process.

Table 4.3 ANOVA of S/N ratios for SR

Effect	Analysis of Variance (SR)				
	SS	df	MS	F	% Contribution
1 Ip	14.5668	2	7.28341	0.407676	0.19139
2 Ton	11.5843	2	5.79219	0.324208	0.152204
3 V	49.9595	2	24.97975	1.398199	0.656406
Residual error	35.7313	2	17.86566		

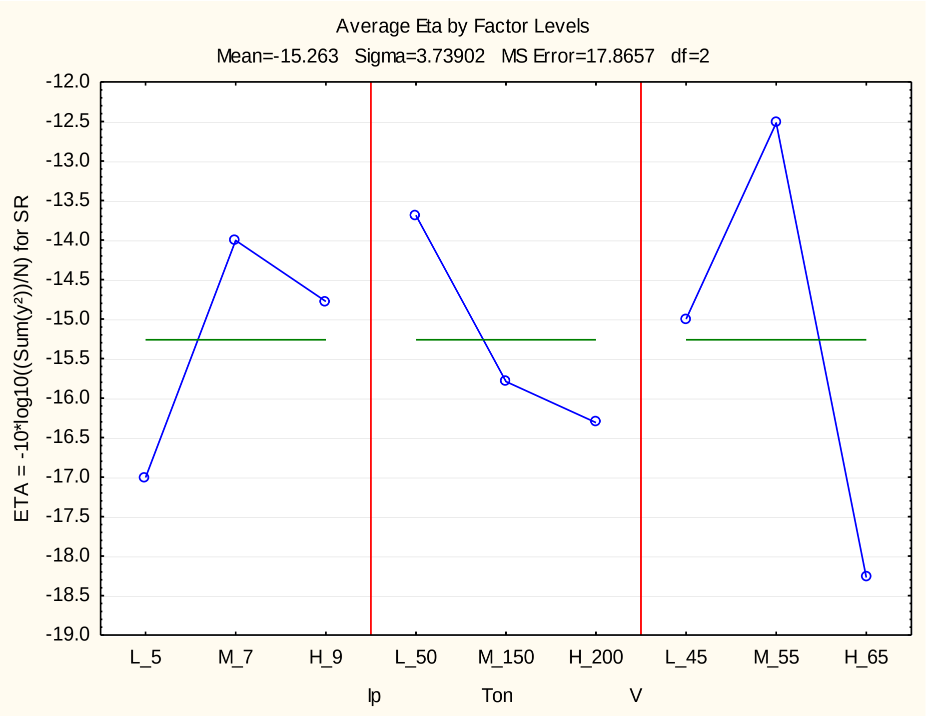
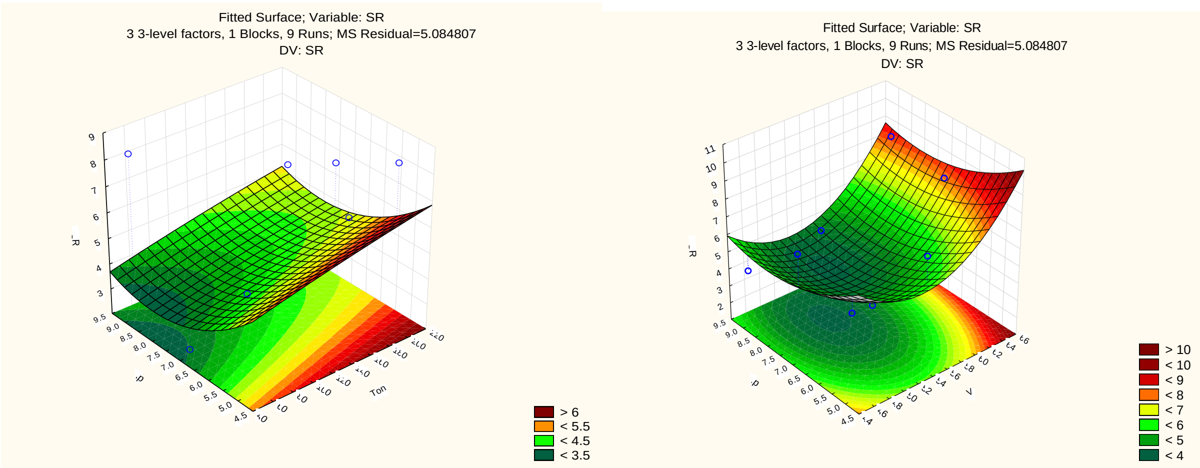


Fig. 4.9: S/N ratio plot of SR

4.4 Surface plots

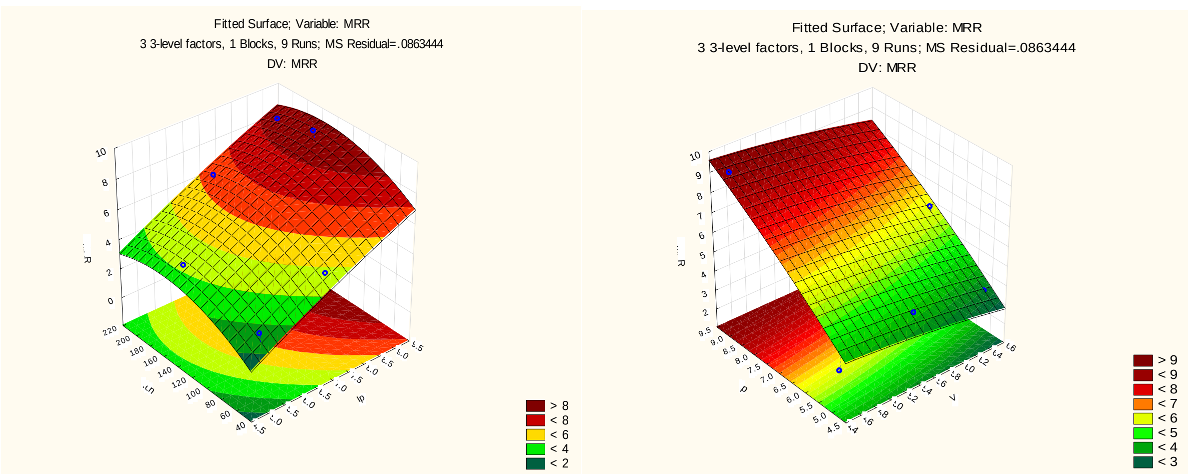
Figure 4.10(a) shows the three dimensional surface plot of surface roughness (SR) against pulse on time (Ton) and discharge current (Ip), when the Ton increases SR increases and Figure 4.10(b) when Ip increases SR decreases. Similarly, when V increases, SR increases and when Ip increases SR has slightly increases shows the impact of voltage on the SR.



(a) (b)

Fig. 4.10 (a) & (b): Three dimensional surface plots of the main effects of Ip, Ton and V

Figure 4.11 (a) & (b) shows that three dimensional surface plot of MRR against pulse on time (Ton) & discharge current (Ip) and Ip & V respectively. However, Ip has greater impact on MRR as compared to Ton and V, in which MRR increases rapidly as the Ip increases.



(a) (b)

Fig. 4.11 (a) & (b): Three dimensional surface plots of the main effects of Ip, Ton and V

Chapter 5

Conclusion

In this investigational experiment on EDM to know the effect of machining outputs taken for consideration are material removal rate and surface roughness of the AISI 304 SS work piece using the solid tungsten carbide tool with side flushing method have been investigated. Both these outputs are important in industrial applications. The conduction of experiment depends upon various parameters settings such as discharge current (Ip), pulse on time (Ton) and voltage (v) have been selected. Based on L_9 orthogonal array by taguchi design was conducted and STATISTICA 9.0 software package was used for analysis of the experiment. The results on outputs are to some extent be authenticated. The following points conclude the experiment are:

1. From the results of MRR we conclude that the discharge current is most significant or influencing factor then pulse on time and at last is voltage on the given input. MRR increased linearly with some extent of current and increases and decreases slightly with pulse on time.
2. In case of surface roughness the voltage is the effective parameter after that current and voltage are less effective on machined work piece.

Chapter 6

Appendix

In this section we are discuss about the experimental used EDM machine parts and equipment which are recommended for conducting the experiments.

For circulation of dielectric there is a reservoir at base, pump and valves for passage used to circulate the dielectric for each run of experiments as shown in figure 6.1.

Fig. 6.1: Dielectric tank at base and pump [Ref. 3]

There is a CNC control system attached over the working tank to facilitate the experiments in controlled manner with power supply unit as shown in figure 6.2.

Fig. 6.2: CNC control and power supply unit [Ref. 3]

The surface roughness values are measured by means of an apparatus portable type profilometer, Talysurf (Model: Surtronic 3+, Taylor Hobson) shown in figure 6.3. It has been taken readings at three points and taken average value of these three readings for SR.

Fig. 6.3: Talysurf (Model: Surtronic 3+, Taylor Hobson) [Ref. 3]

The calculation of material removal rate has been done by using electronic sense of balance weight machine as displayed in figure 6.4. For each weight measurement first soak the work piece from paper or cloth to prevent from extra weight measurement. This machine having capability measure weight up to 300 g and accurateness is 0.001 g.

Fig. 6.4: Digital weight balance machine (SHINKO DENSHI Co. LTD, JAPAN, Model: DJ 300S) [Ref. 3]

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